

# Using a Steady State Model of an Aluminum Reduction Cell to Investigate the Impact of Design Changes

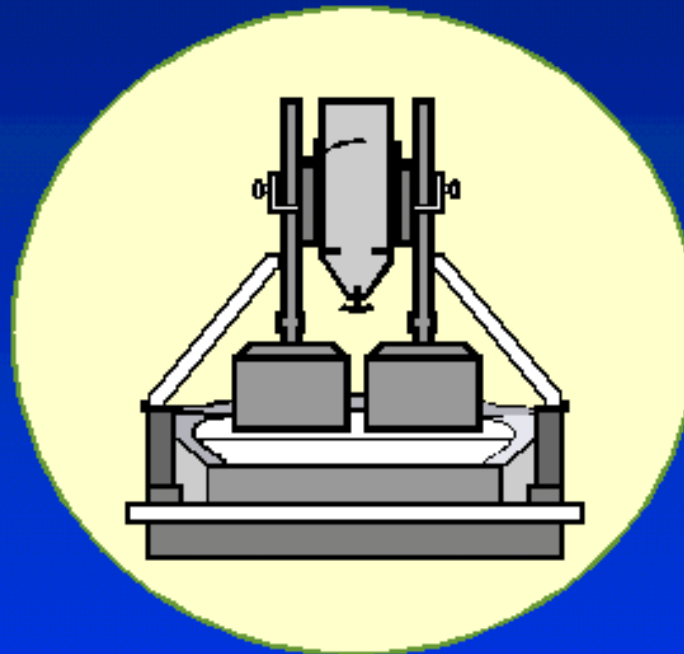
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# Steady State Model Program Overview

## Idealized system consists of the :

- Liquid Zone  
(Bath and Metal)
- Solidified Ledge



## Solution strategy consists of :

Internal Heat - Heat Loss  
 $= 0$

Standard Newton  
Raphson algorithm

**Process Model : Heat Balance Equation**

# Internal Heat

- **Evaluated by computing the voltage break down:**
  - Bath Composition
  - Bath Resistivity
  - Bath Liquidus
  - Current Efficiency
  - Bath Voltage
  - Electrolysis Voltage
  - Equivalent Voltage to Make Metal

# Global Heat Loss

- Four surfaces are defined for losing heat:
  - Anode Panel
  - Cathode Panel
  - Freeze Adjacent to Bath Layer
  - Freeze Adjacent to Metal Layer



## Choice of Root Search "Variable"

- Any of the following parameters can be selected as the "variable" of the root search algorithm :

- |  |                                  |
|--|----------------------------------|
| - Amperage of the cell                               | - Length of the anodes           |
| - Anode to cathode distance                          | - Width of the anodes            |
| - Concentration of excess $\text{AlF}_3$             | - Heat loss of anode panel       |
| - Concentration of dissolved $\text{Al}_2\text{O}_3$ | - Anode voltage drop             |
| - Concentration of $\text{CaF}_2$                    | - Length of the cell cavity      |
| - Concentration of $\text{LiF}$                      | - Width of the cell cavity       |
| - Concentration of $\text{MgF}_2$                    | - Heat loss of the cathode panel |
| - Height of bath                                     | - Cathode voltage drop           |
| - Height of metal                                    | - Cell operating temperature     |

# Example of Application

ARC/DYNAMIC : Steady State Solution

Convergence Criteria

☒ Percent difference between Qin & Qout 1.e-006 %

☐ Absolute difference between Qin & Qout 1. kW

☐ Percent change of the target variable 0.1 %

☐ Absolute change of the target variable 1.e-003 cm

Maximum number of iterations 20

Relaxation factor (<=1) 1.

Exit

Solve

Print ...

List of Variables

Name	Value
*ACD	4
CALFEX	8.5
CALOSOL	2
CCAF	3
CELLAMP	300
CLIF	0
CMGF	0
HBATH	20
HFBTHFRZ	650


ACD (cm)

Value: 4.0

Description ...

☒ Set as target

ARC/DYNAMIC

 Solution converged after 3 iterations.  
%ABS(Qin-Qout)=1.00272e-012, Tol=1e-006

Calculated value of ACD= 4.9951 cm  
Average AI203 feeding rate = 177.8 kg/hr  
Average AIF3 feeding rate = 1.12377 kg/hr  
Target cell resistance = 8.7342 micro-Ohm

OK

# Example of Application

ARC/DYNAMIC : Steady State Solution

Convergence Criteria

☒ Percent difference between Qin & Qout 1.e-006 %

☐ Absolute difference between Qin & Qout 1. kW

☐ Percent change of the target variable 0.1 %

☐ Absolute change of the target variable 0.3 kA

Maximum number of iterations 20

Relaxation factor (<=1) 1.

Exit

Solve

Print ...

List of Variables

Name	Value
ACD	4
CALFEX	8.5
CALOSOL	2
CCAF	3
*CELLAMP	300
CLIF	0
CMGF	0
HBATH	20
HFBTHFRZ	650


CELLAMP (kA)

Value: 300.

Description ...

☒ Set as target

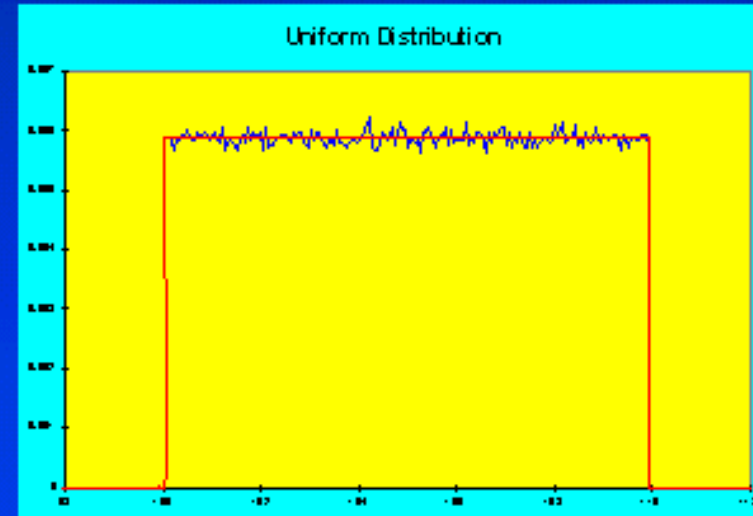
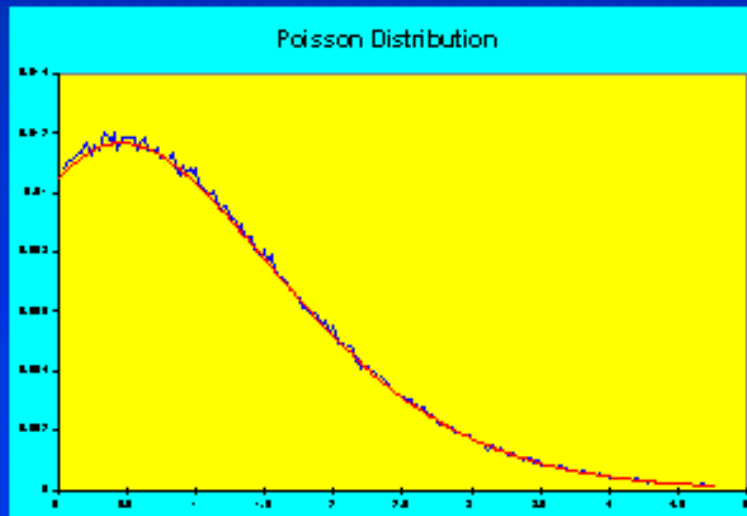
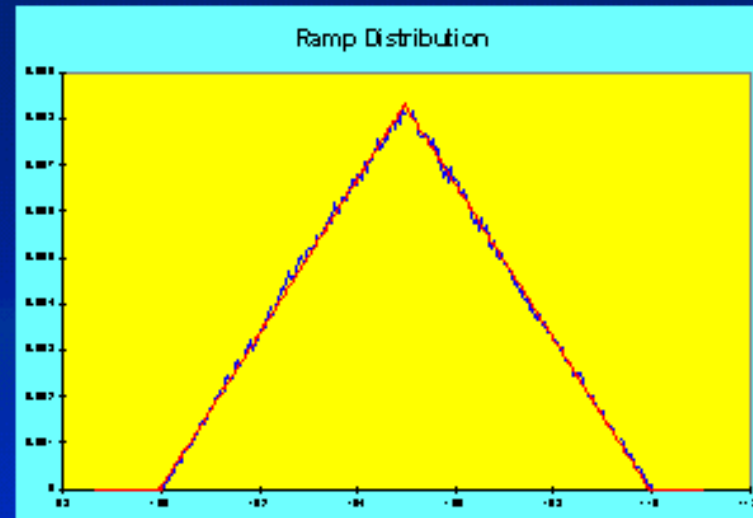
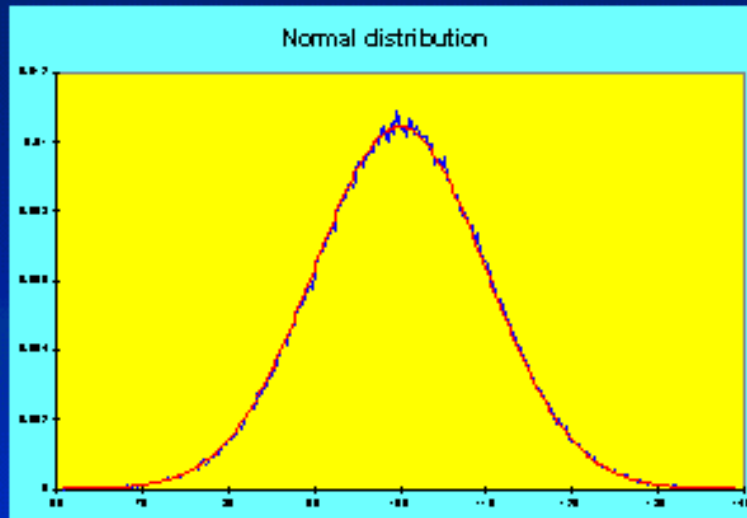
ARC/DYNAMIC

 Solution converged after 3 iterations.  
%ABS(Qin-Qout)=9.65816e-010, Tol=1e-006

Calculated value of CELLAMP= 323.259 kA  
Average Al2O3 feeding rate = 192.5 kg/hr  
Average AlF3 feeding rate = 1.19096 kg/hr  
Target cell resistance = 7.6677 micro-Ohm

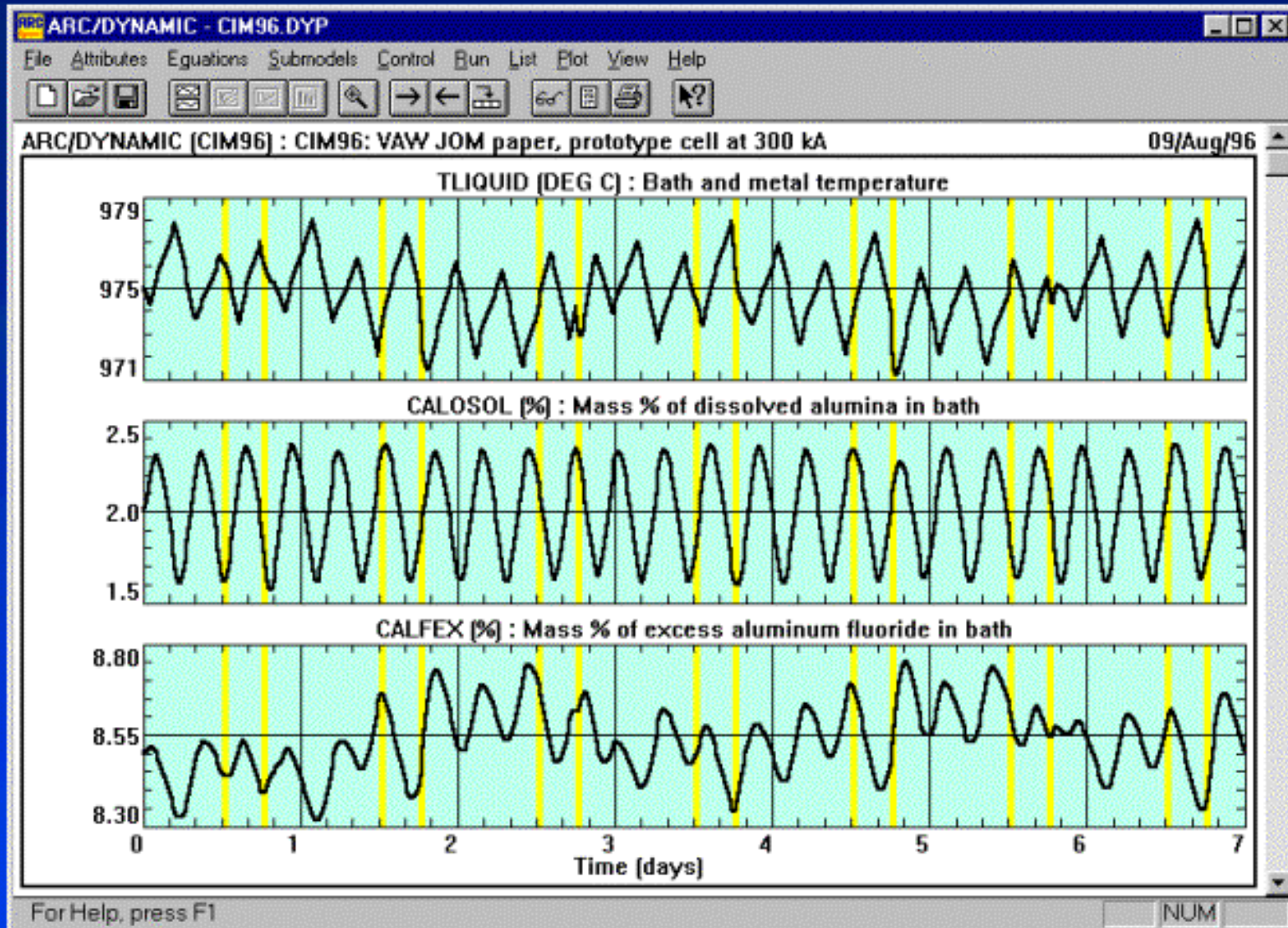
OK

# Monte Carlo Input Parameter Distributions



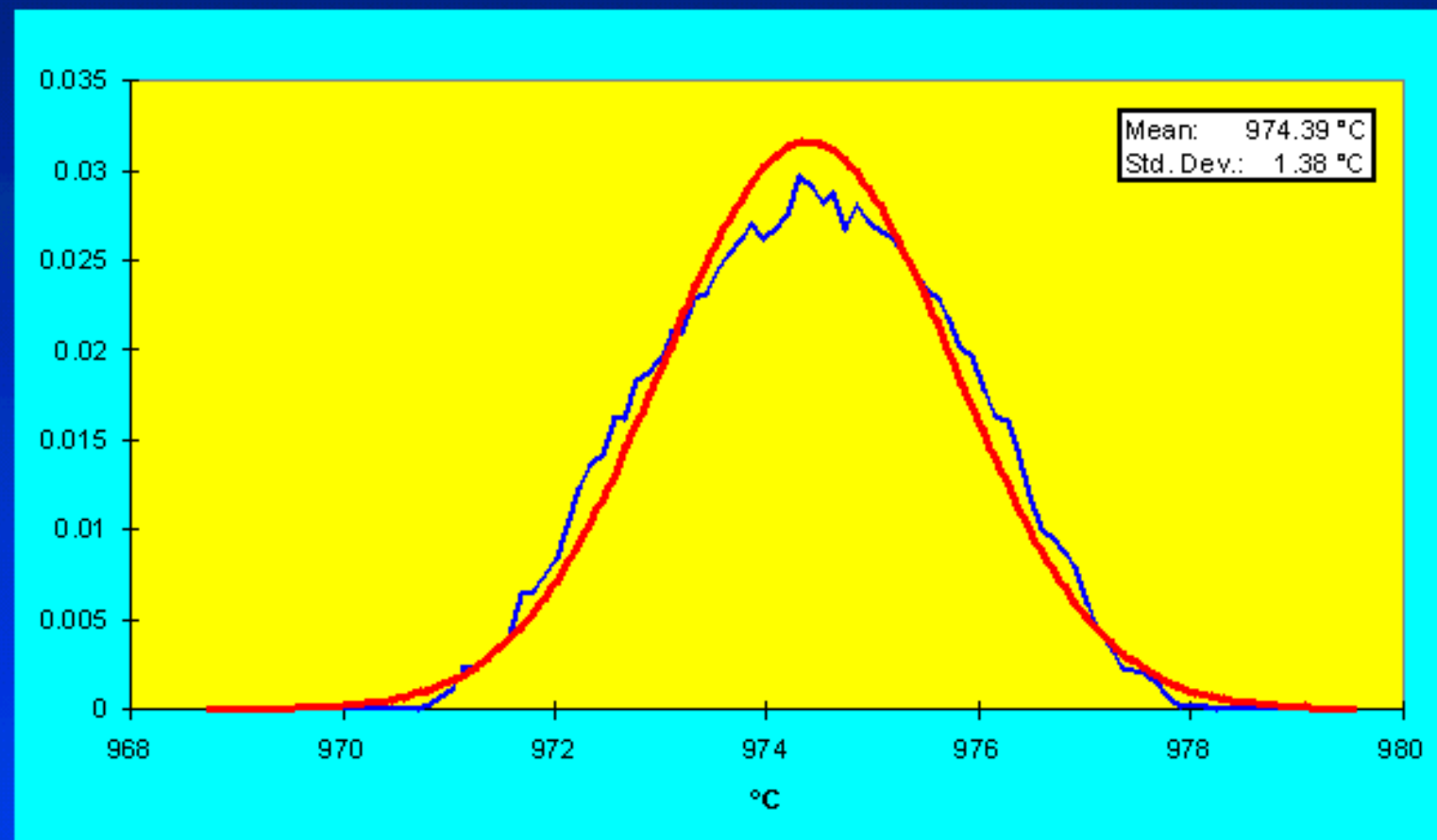


# Analysis of Dynamic Response

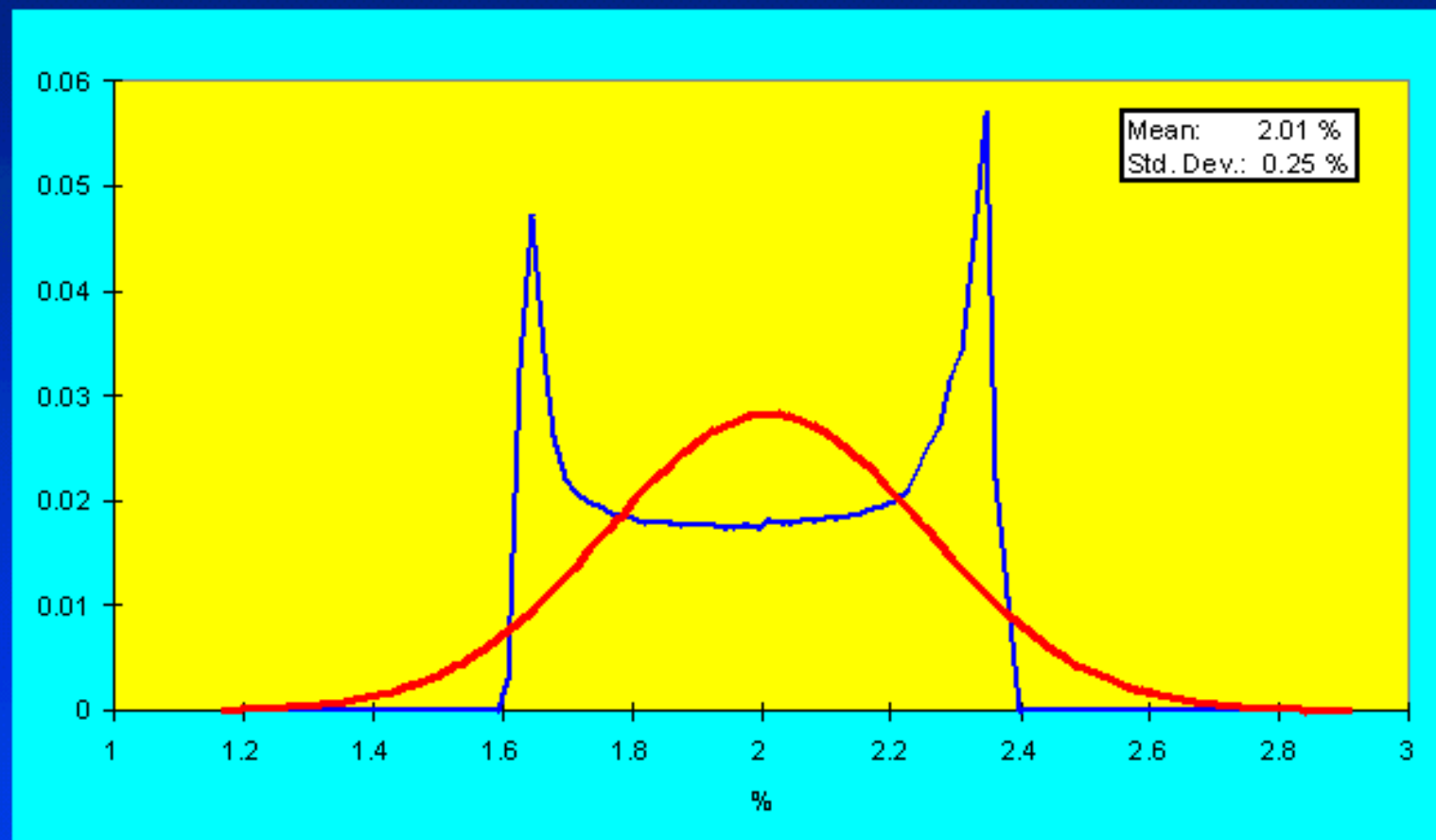




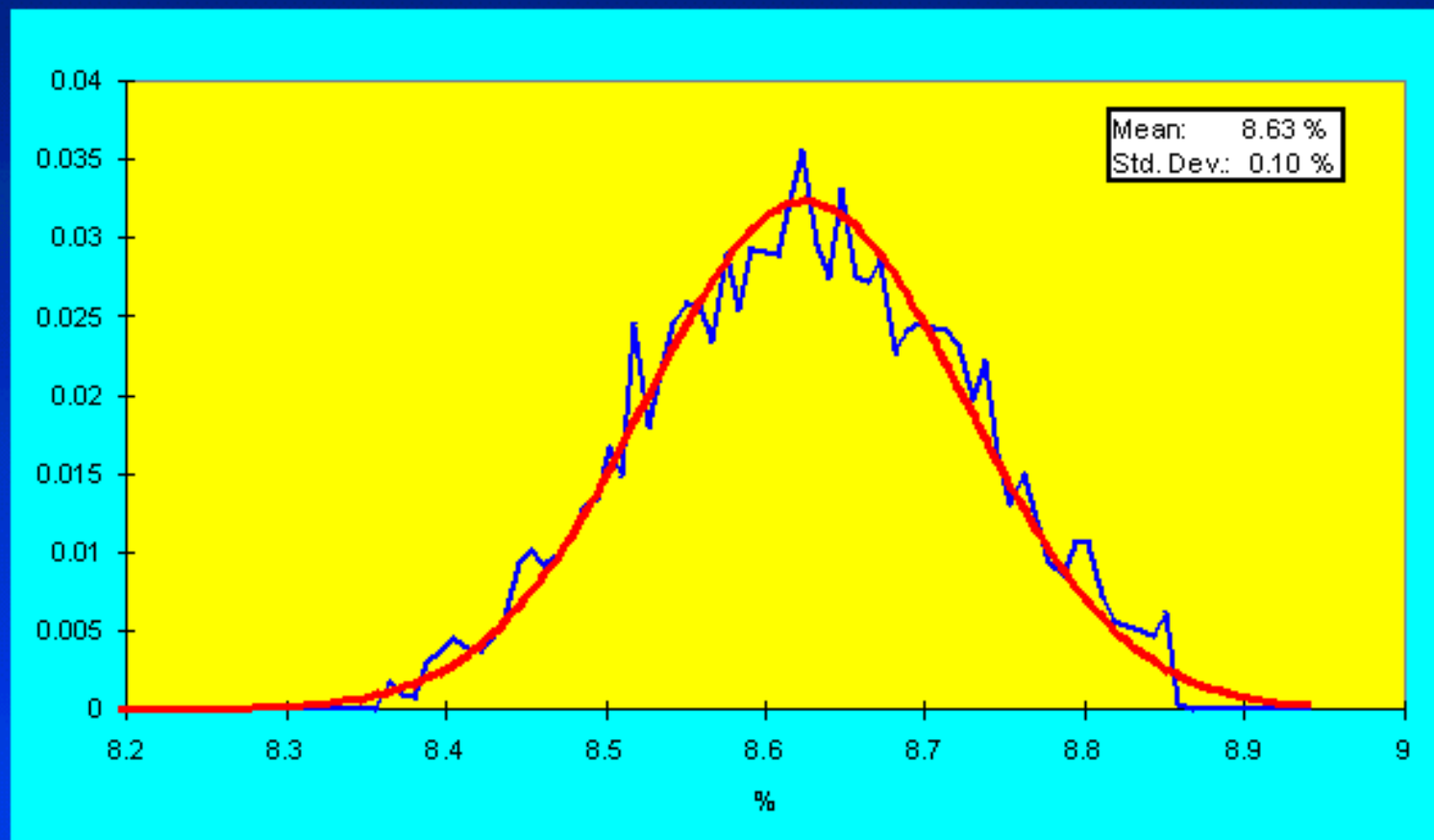
# Dynamic Temperature Distribution



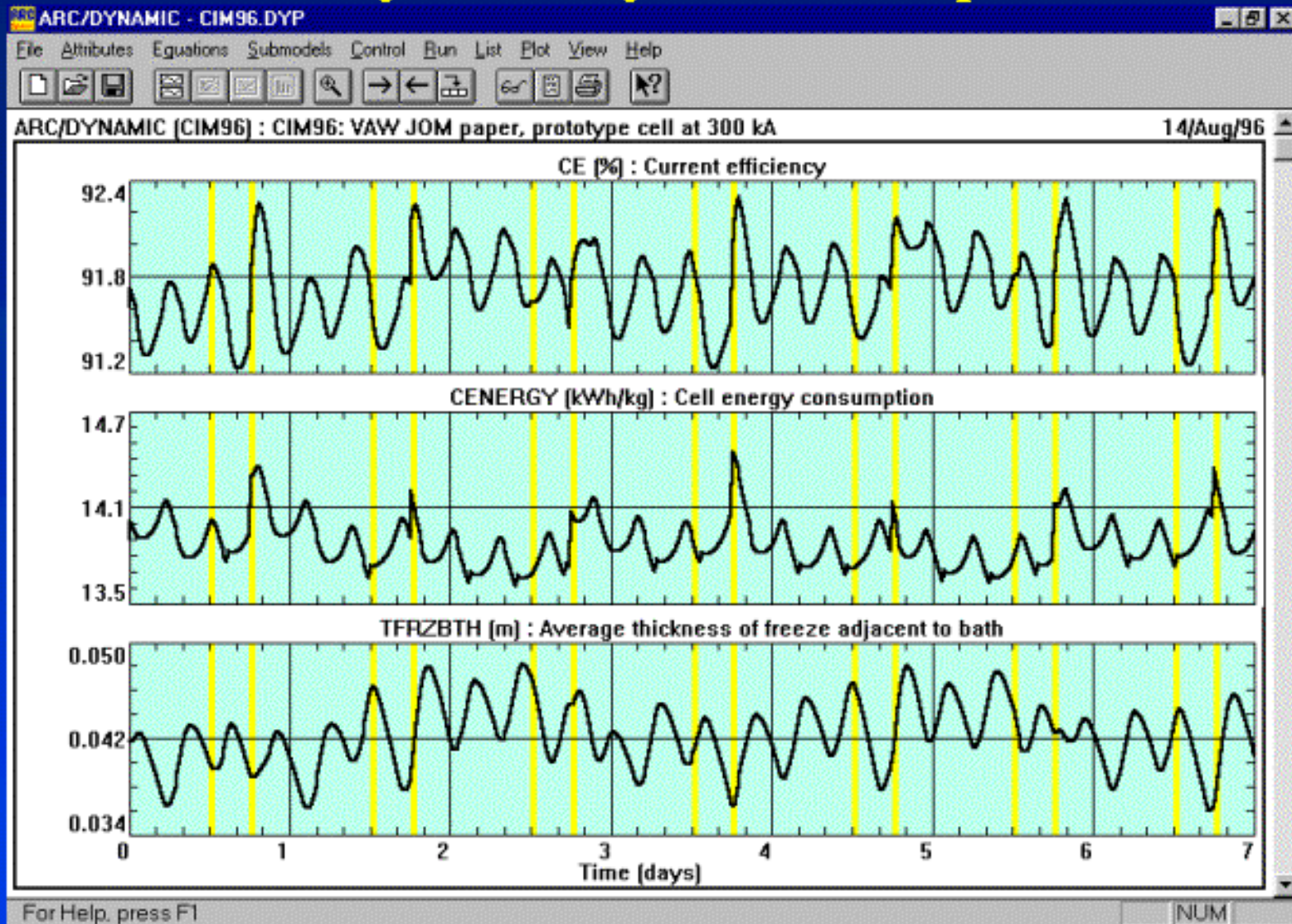
## Dynamic Dissolved $\text{Al}_2\text{O}_3$ Distribution



## Dynamic Excess $\text{AlF}_3$ Distribution

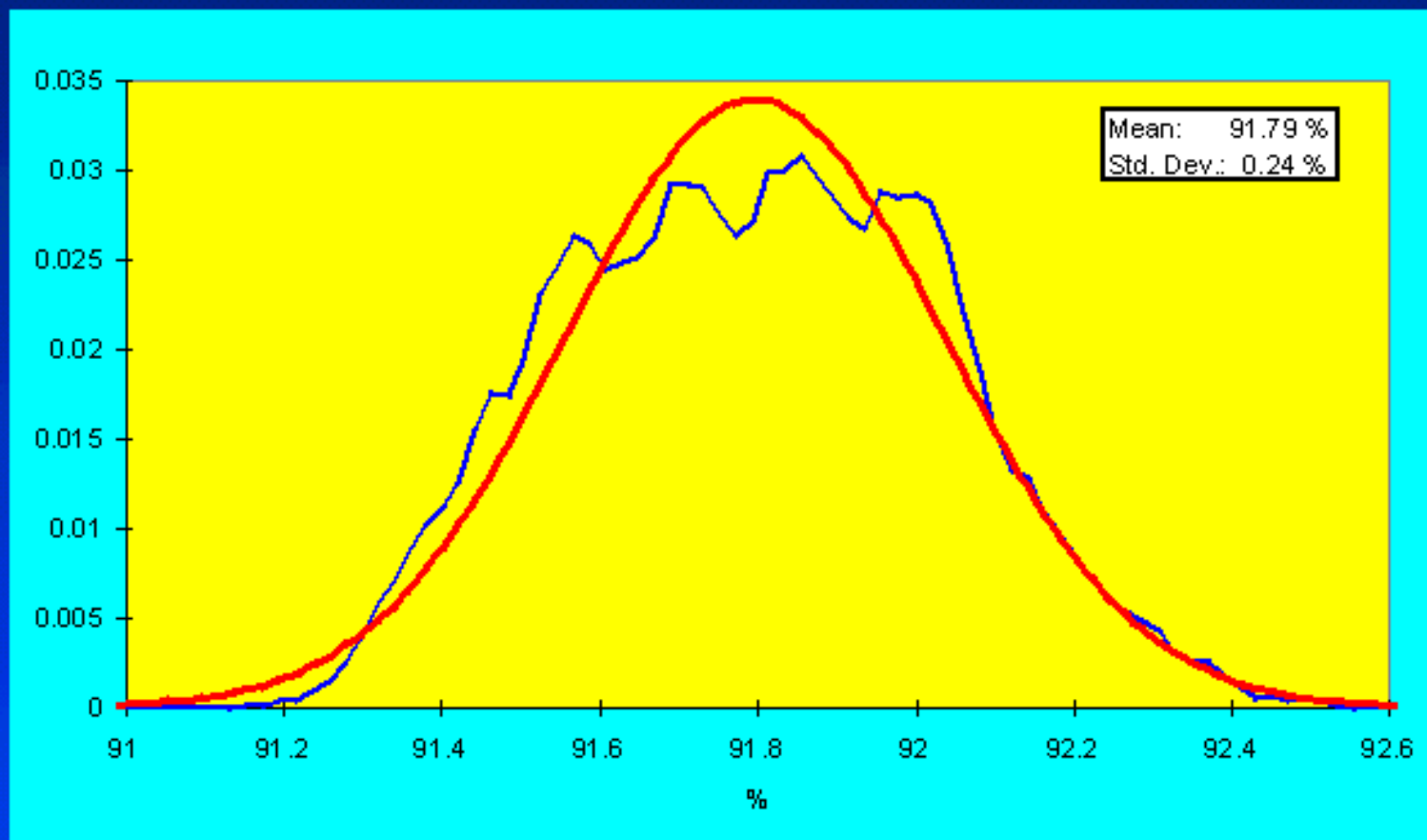


# Analysis of Dynamic Response



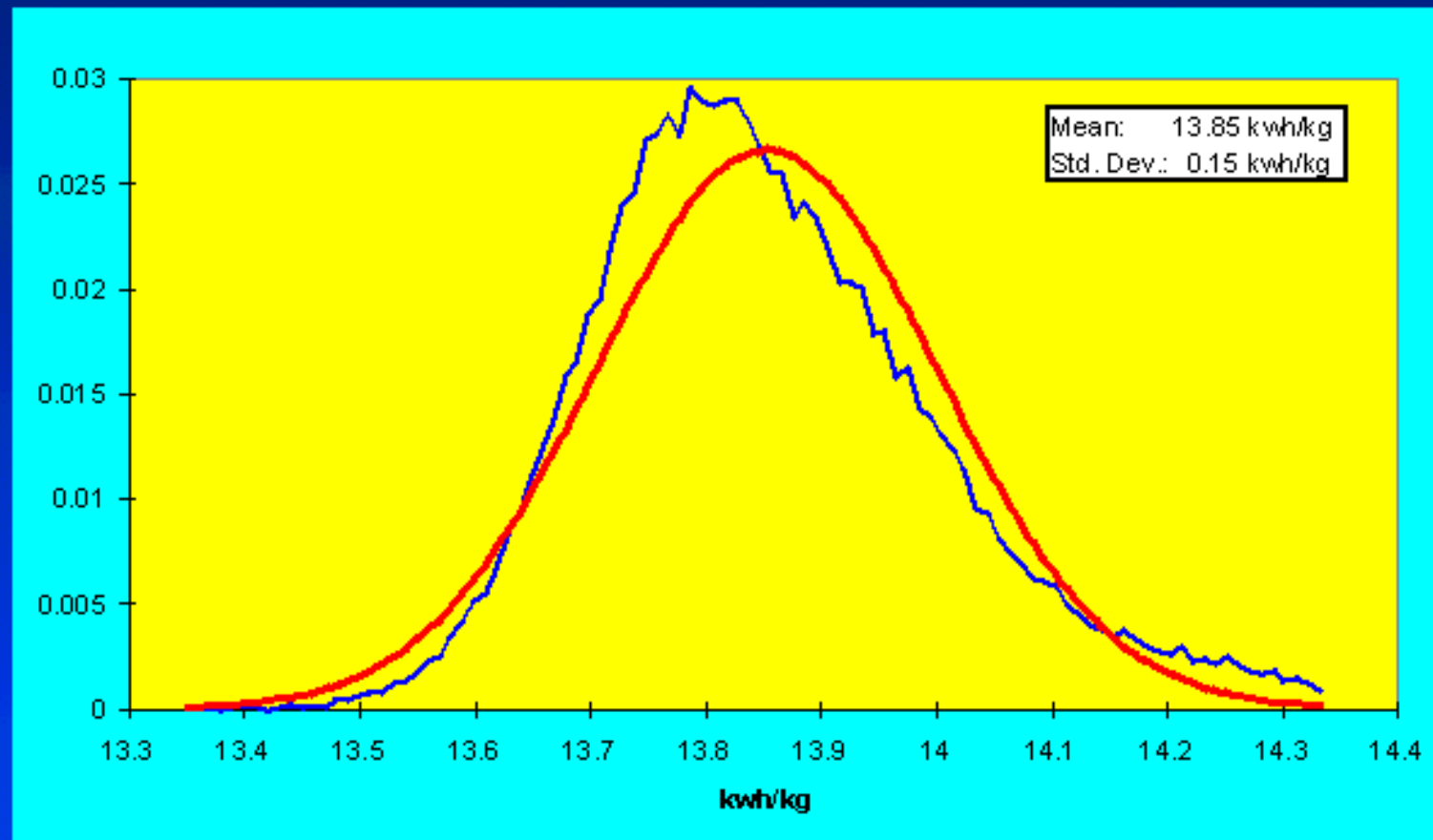


# Dynamic Current Efficiency Distribution

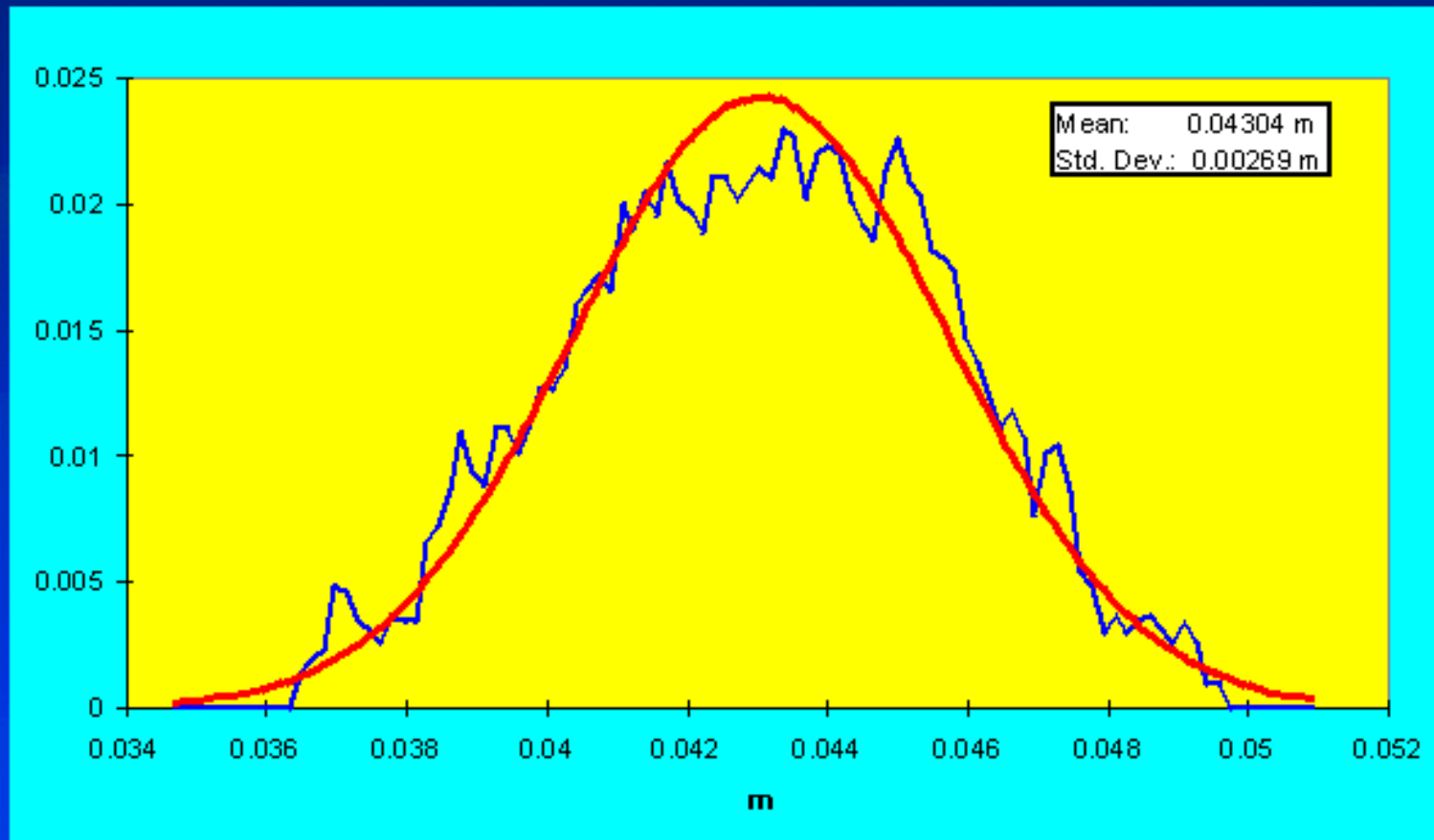




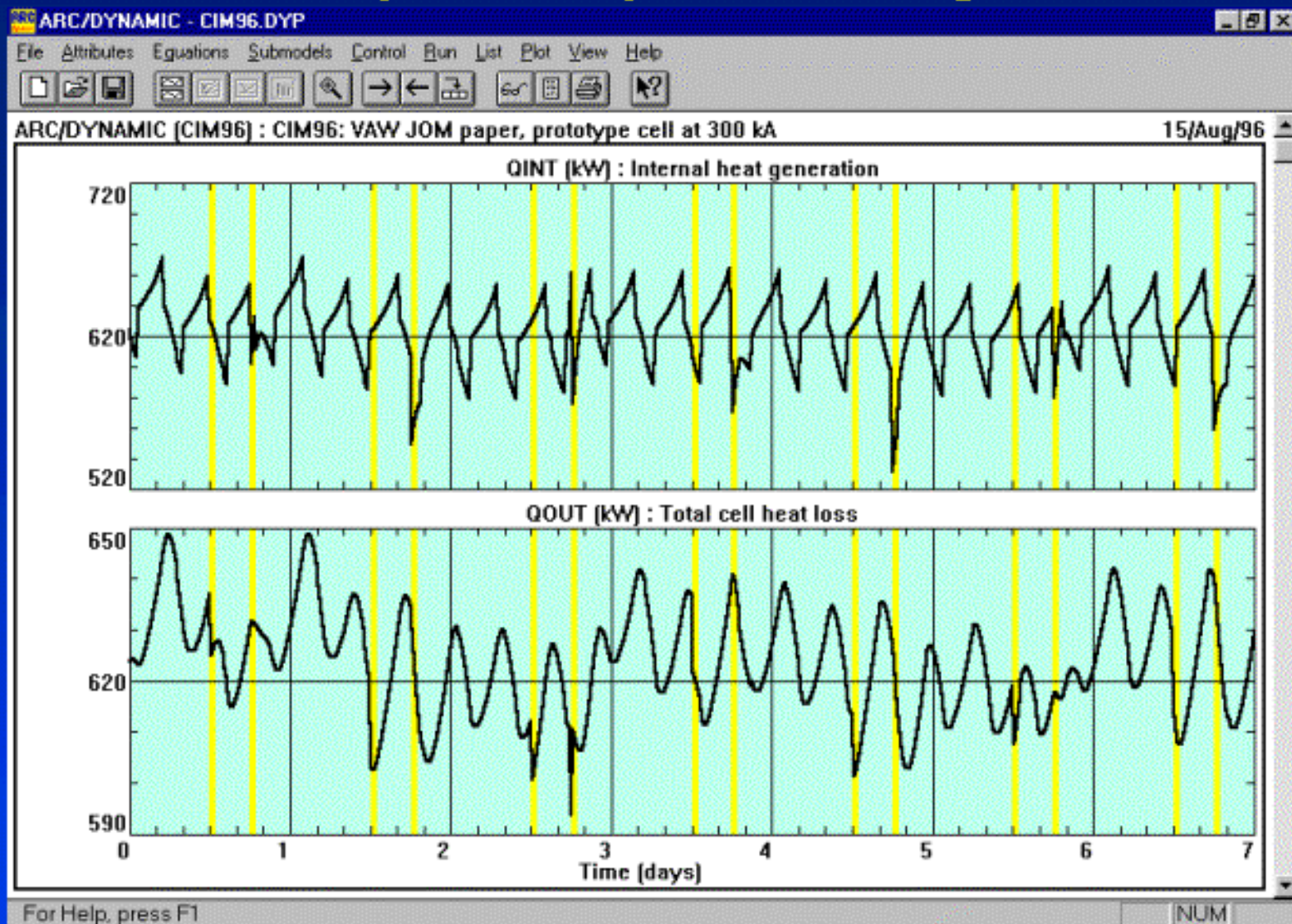
# Dynamic Energy Consumption Distribution



# Dynamic Freeze Thickness Distribution



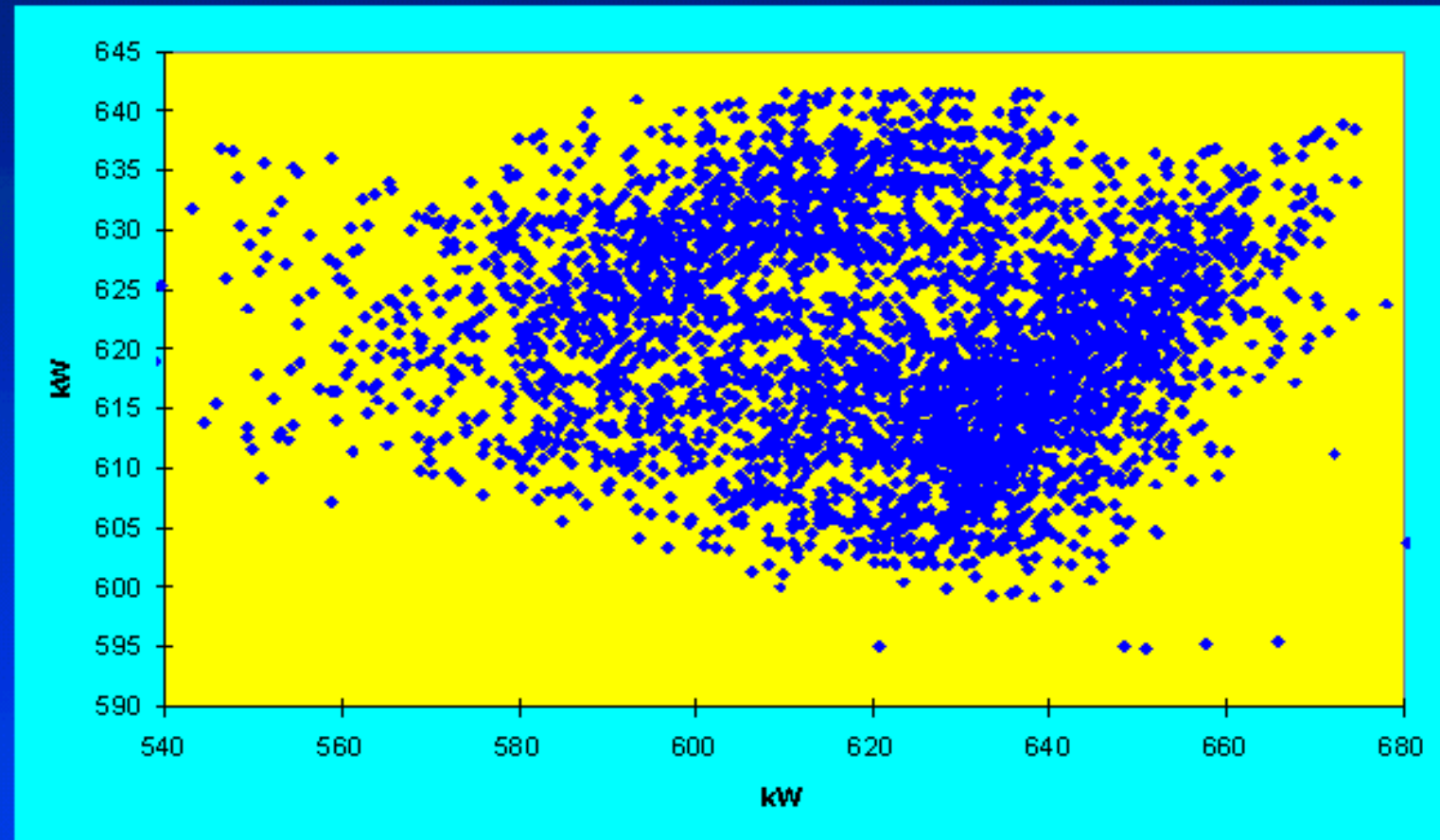
# Analysis of Dynamic Response



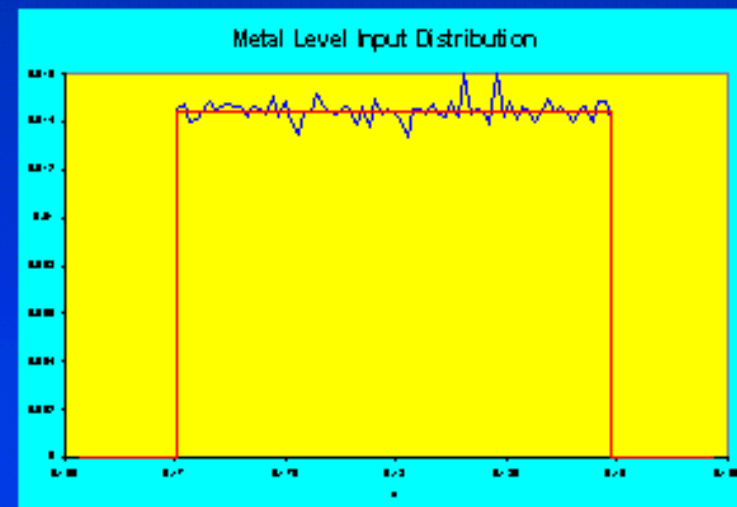
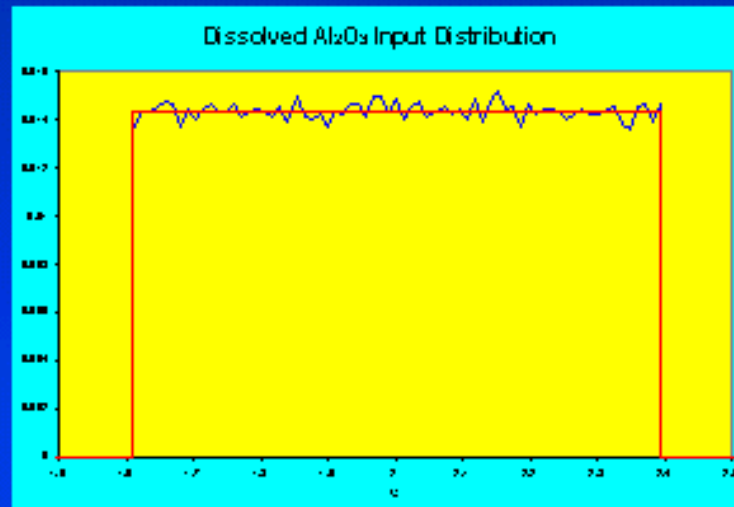
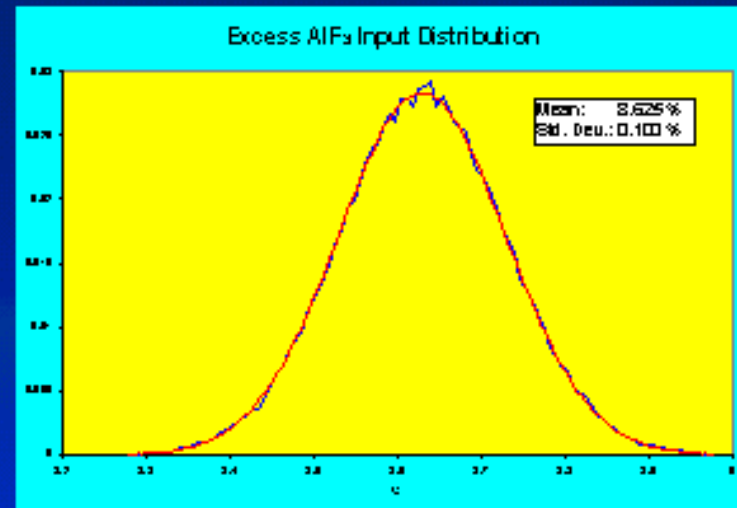
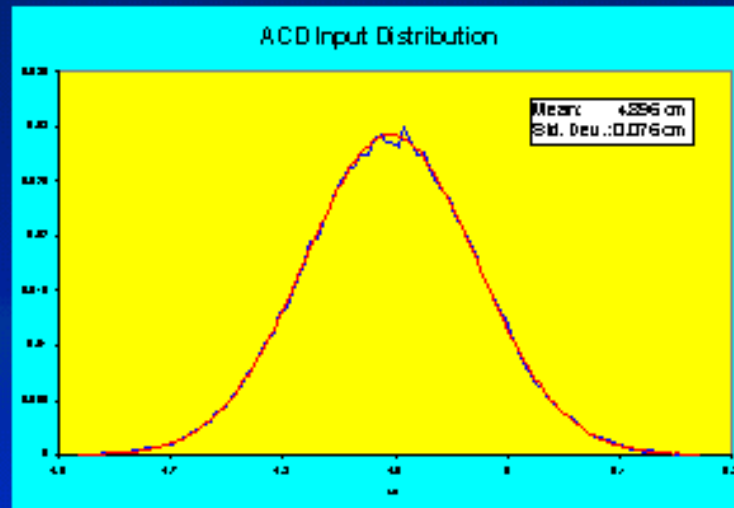


# Dynamic Solution

## Heat Loss vs Internal Heat

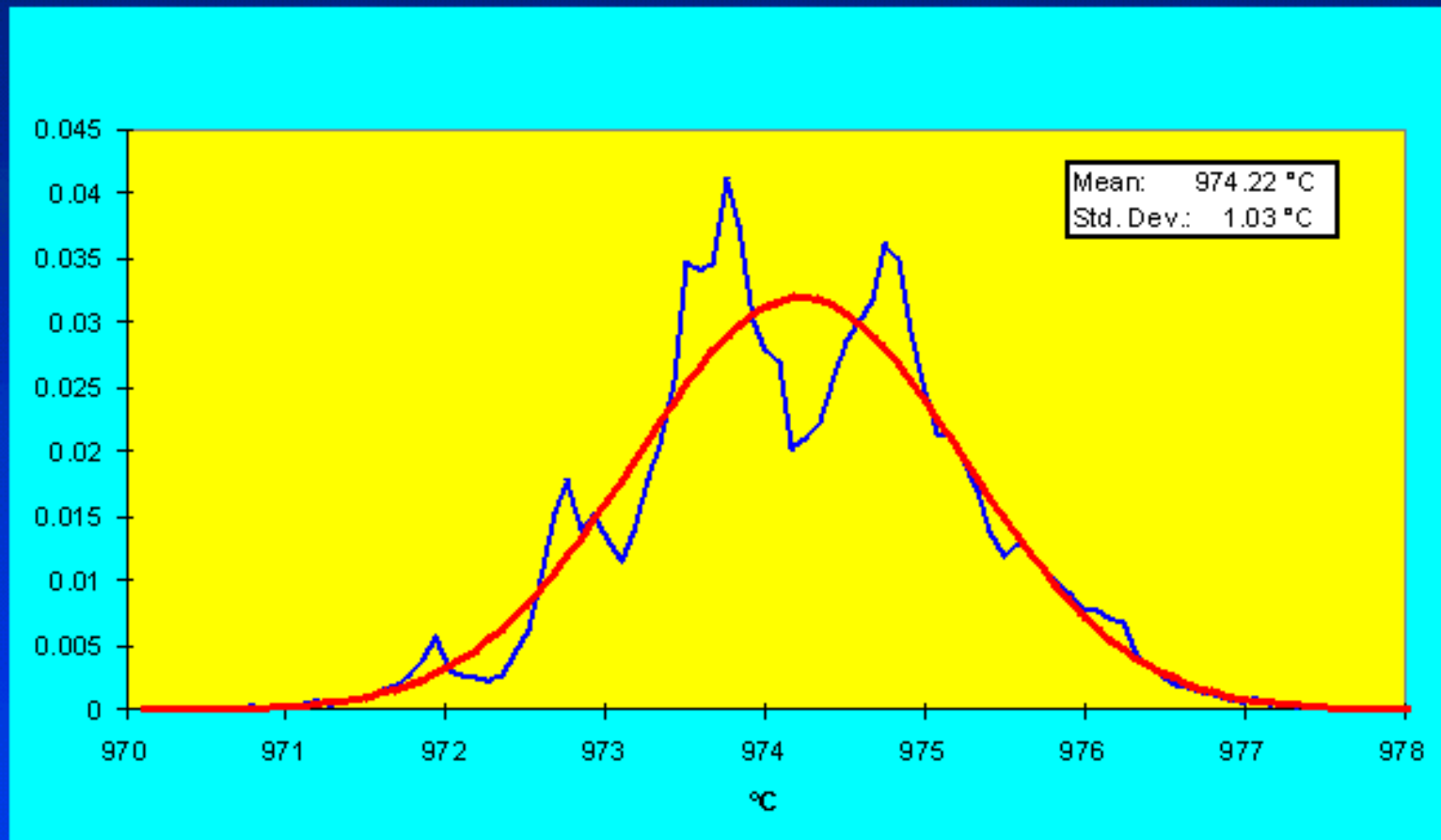


# Example of Monte Carlo Input Distributions

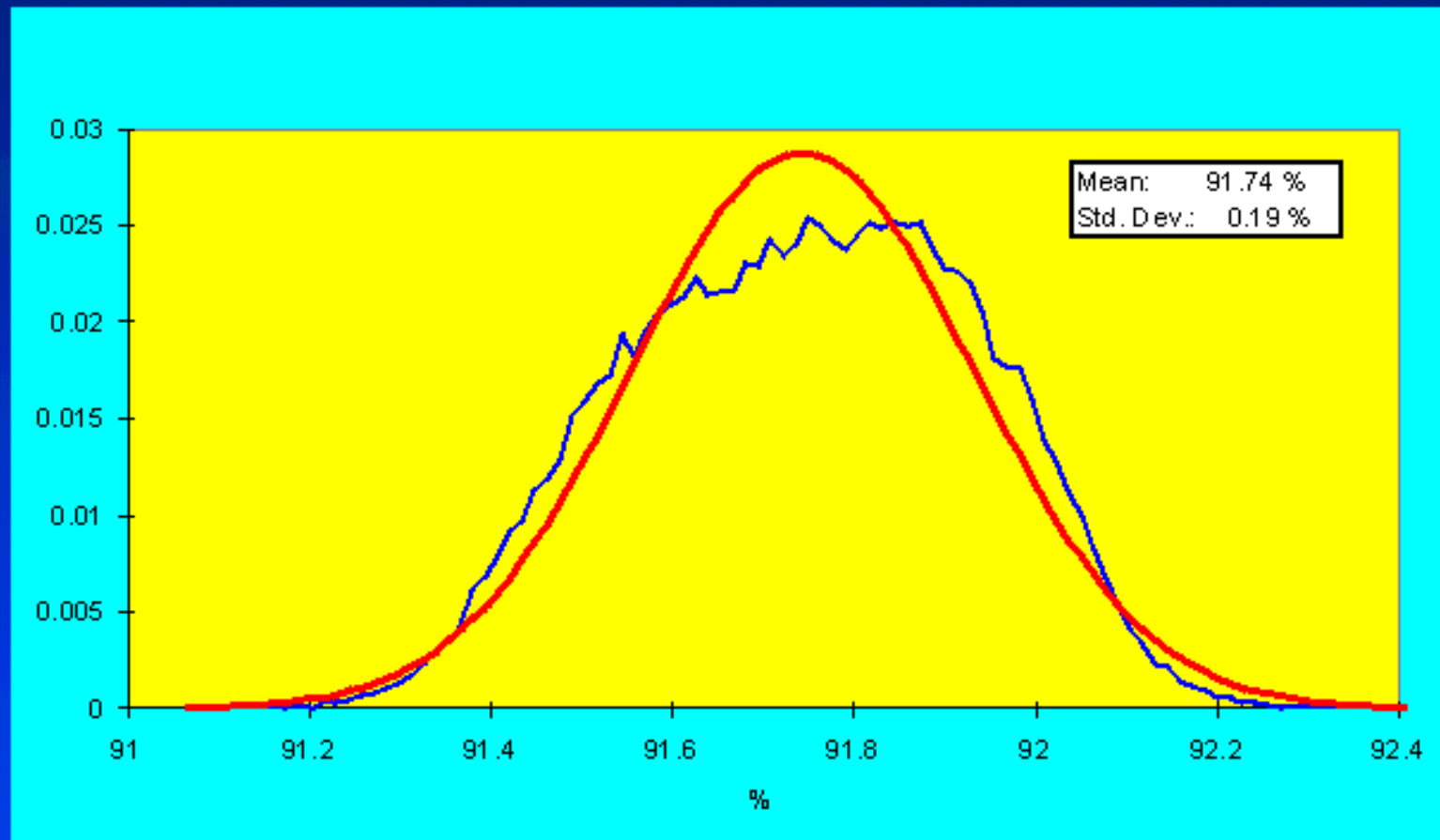




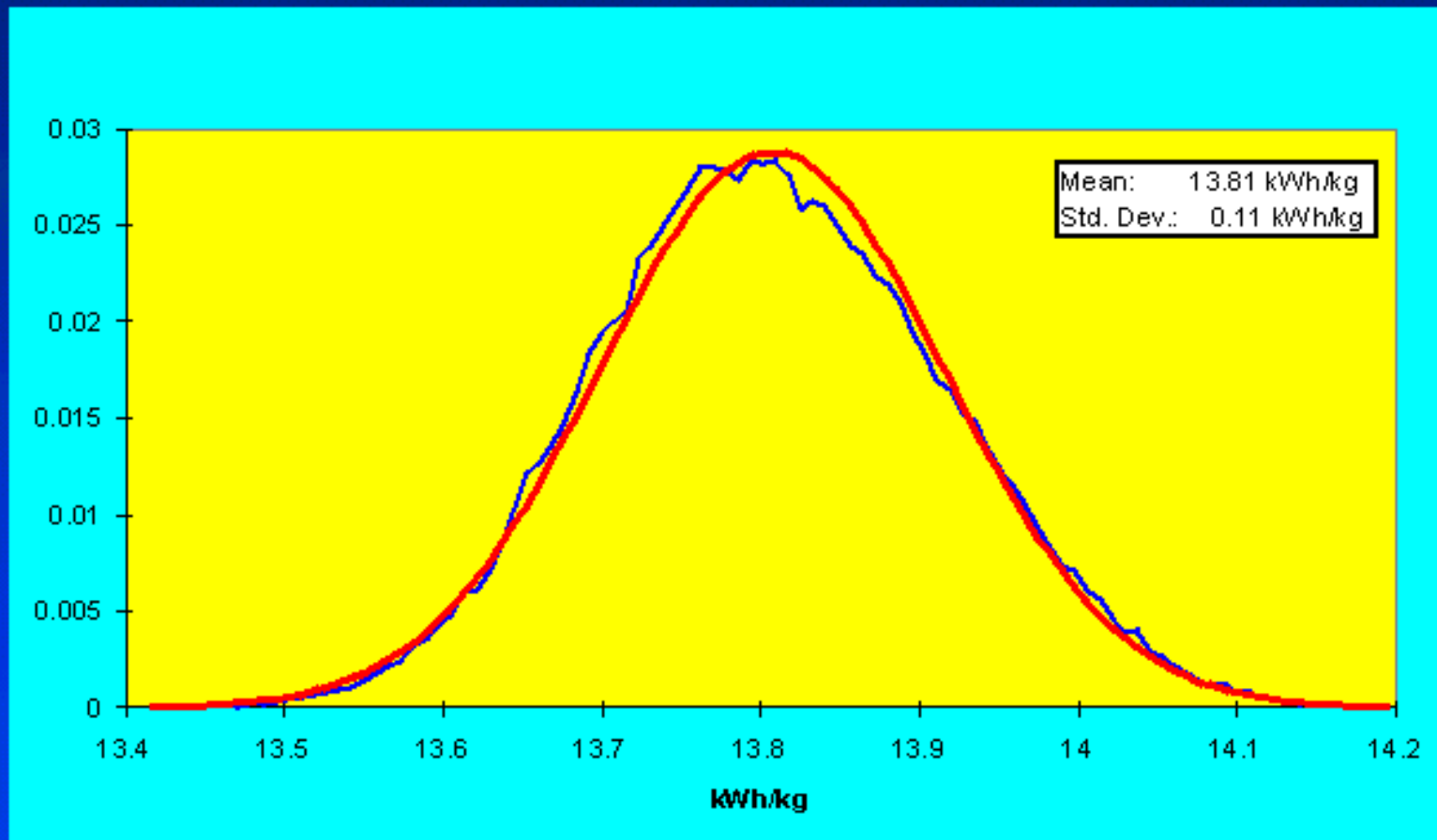
# Monte Carlo Output Temperature Distribution



# Monte Carlo Output Current Efficiency Distribution

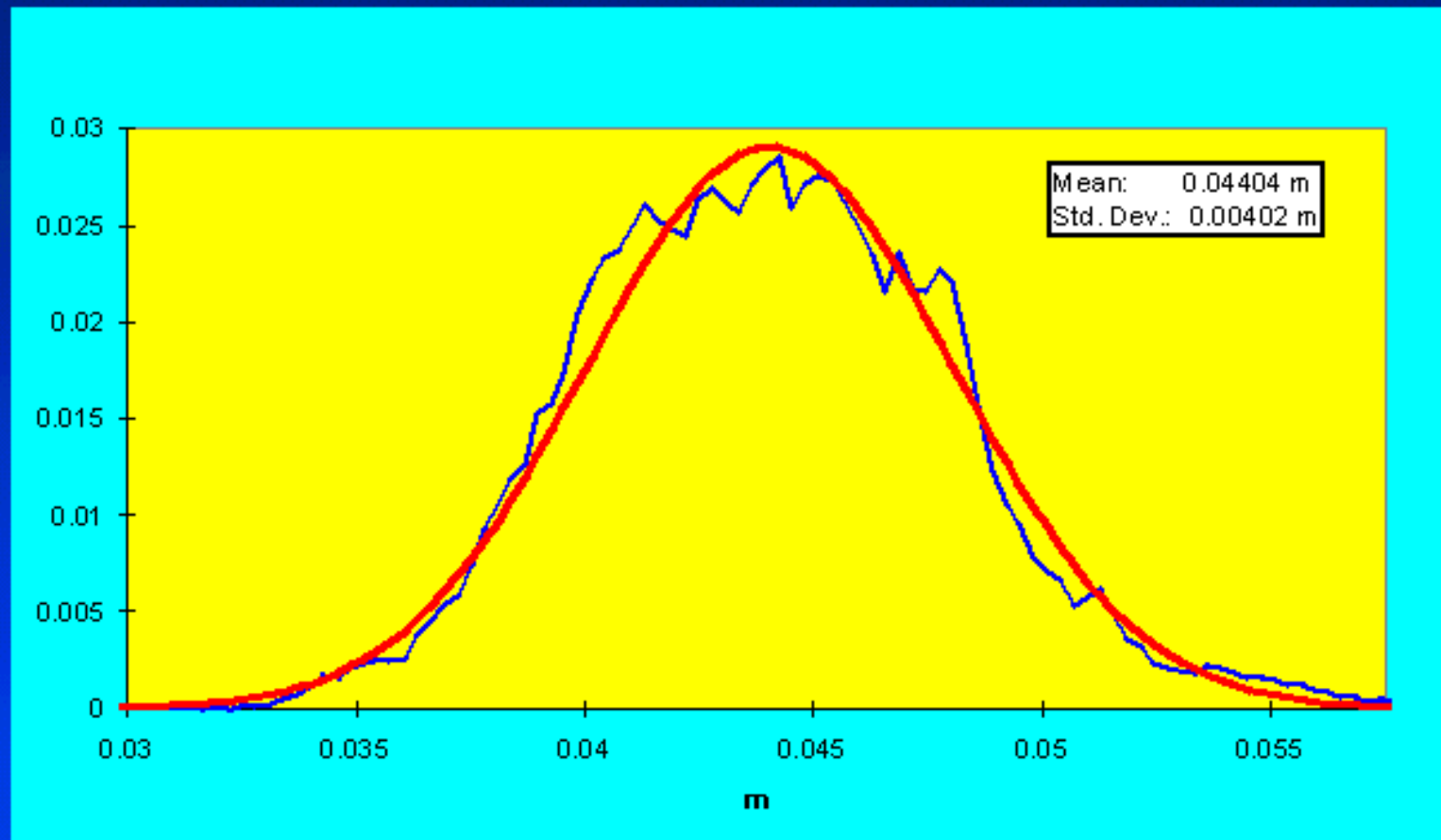


# Monte Carlo Output Energy Consumption Distribution



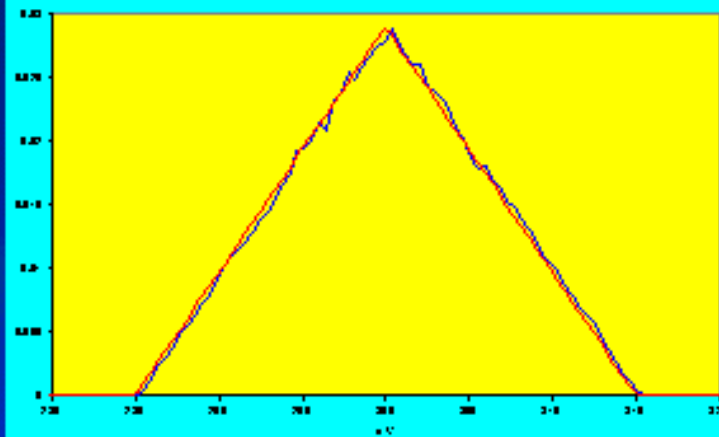
# Monte Carlo Output

## Freeze Thickness Distribution

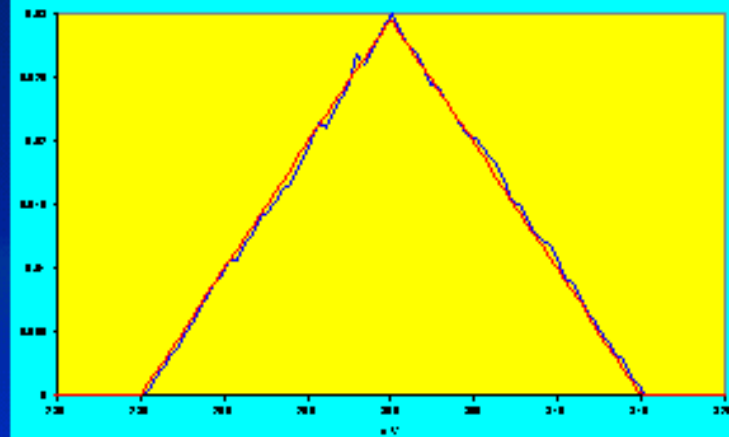


# Sensitivity Study Input Distributions

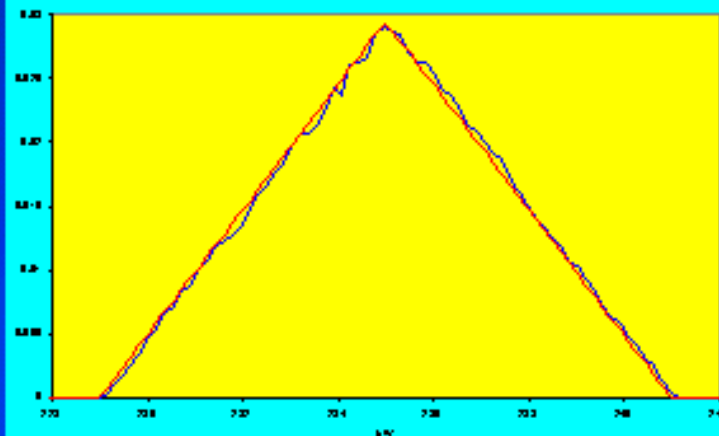
Anode Voltage Drop Input Distribution



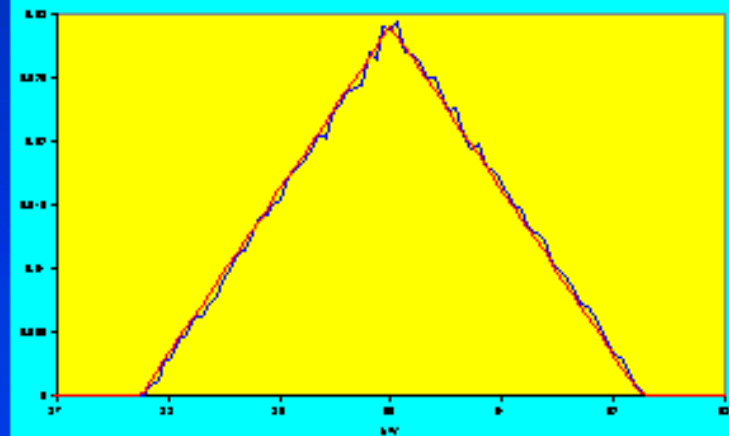
Cathode Voltage Drop Input Distribution



Anode Panel Heat Loss Input Distribution



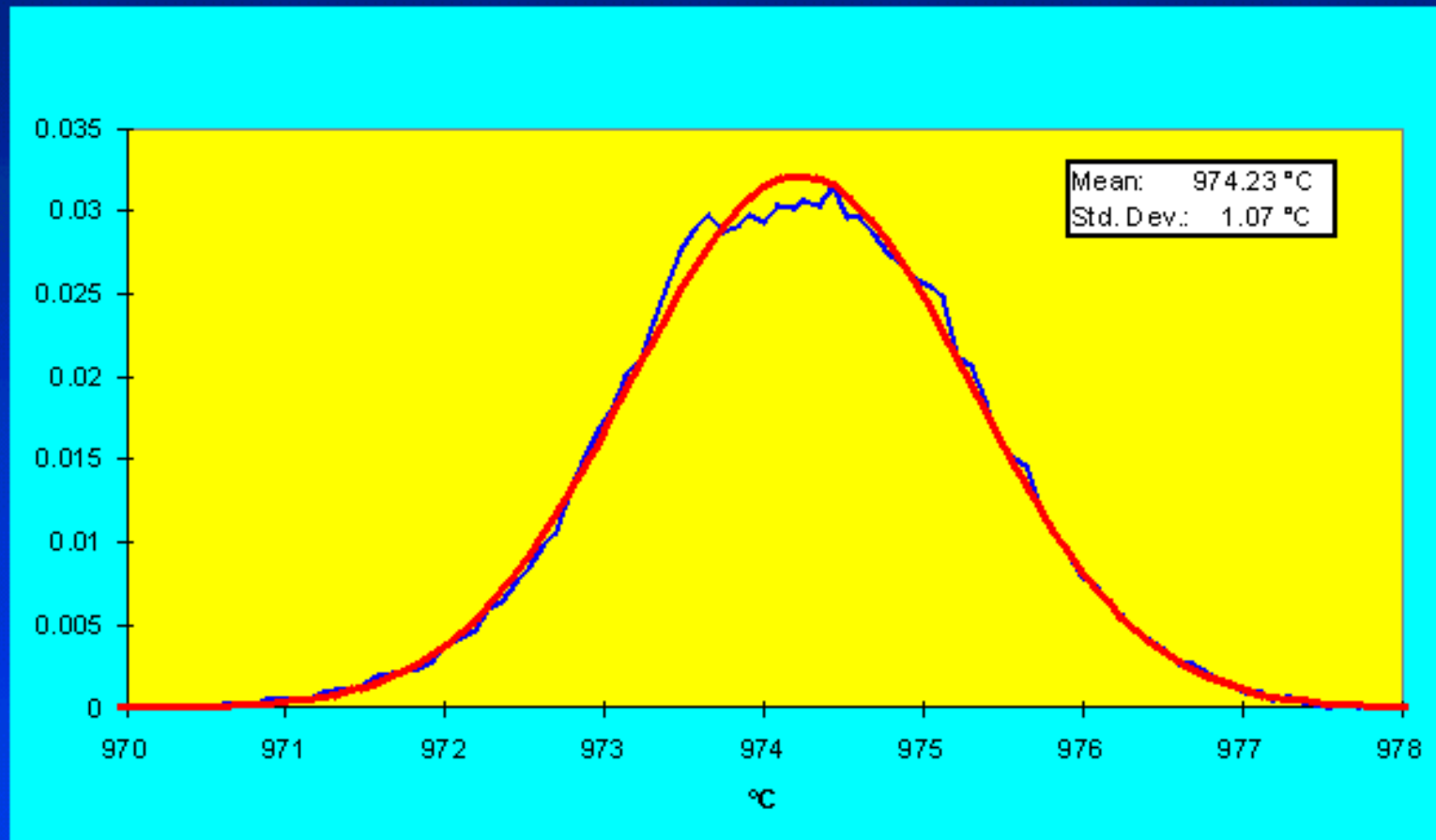
Cathode Panel Heat Loss Input Distribution





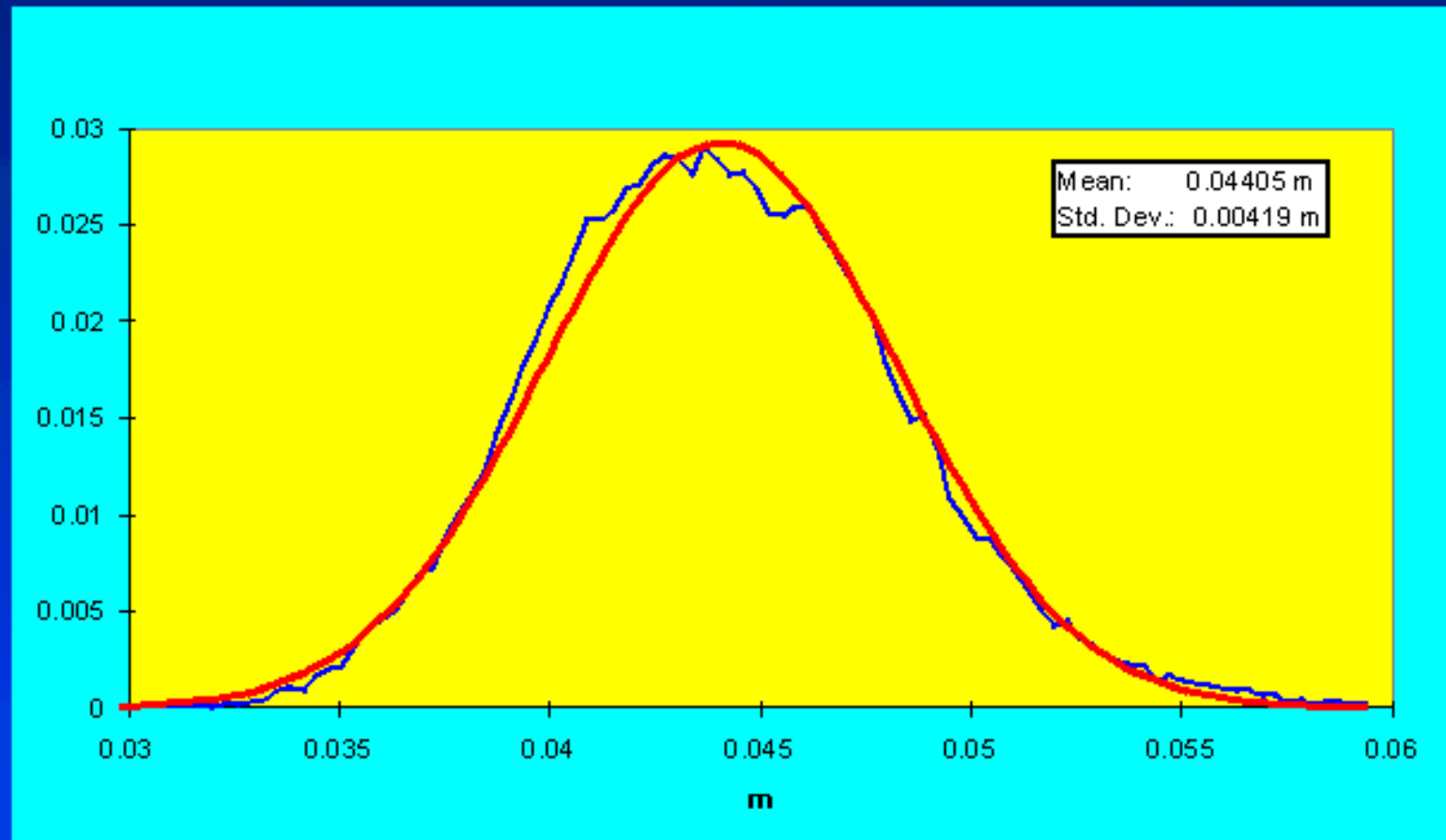
# Sensitivity Study Output

## Temperature Distribution



# Sensitivity Study Output

## Freeze Thickness Distribution



## Summary of Outputs Distribution Results

	Dynamic		Monte Carlo		Sensitivity Study	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Temperature	974.39	1.38	974.22	1.03	974.23	1.07
CE	91.79	0.24	91.74	0.19	91.74	0.19
kwh/kg	13.85	0.15	13.81	0.11	13.81	0.11
Frz. Thick.	4.304	0.269	4.404	0.402	4.405	0.419

# Conclusions

- An enhanced program has been developed to model the steady state behavior of reduction cells.
- The program can be used to perform Monte Carlo analysis by assigning probability functions to input parameters.
- By using input parameters distributions that mimic those obtained from dynamic analysis, it is possible to use a Monte Carlo analysis to reproduce output dynamic analysis distributions.
- By adding input distributions for design variables, it is possible to perform design sensitivity analysis or risk assessment analysis.
- The effect of a  $\pm 5\%$  accuracy on design parameters was demonstrated to have a minor impact on the obtained output distributions.